HIRN'S AND REEVE'S ANALYSIS APPLIED TO THE HAMILTON CORLISS ENGINE

R. MARSHALL TRUITT.

Hirns Analysis
Applied to the Hamilton Corliss Engine.

This analysis developed by Hirn and applied by Prof. V. Dwelshauvers-Dery, is a calorimetric method of investigating the interchange of heat between the cylinder walls, and the steam, and also the amount of heat transferred into work.

The cylinder walls and their susceptibility to conduct heat, exert a considerable influence in the performance of an engine. By means of the cylinder walls heat is extracted from the steam, stored up during one part of the stroke or

radiated to the external air if the cylinder is not well jacketed, and finally the heat remaining in the walls returning to the steam at still another part of the stroke.

Although these heat changes are of a complex nature and it would seem natural that a moderate interval of time would be necessary for their completion yet experimentors have shown that this cycle is gone through in the cylinder of a rapidly rotating engine.

The principle of Hirn's analyses is as follows:- The number of heat units supplied to an engine is determined by measuring the pressure, quality and weight of steam at the beginning of the

stroke, and at the end of the stroke the number of heat units remaining by measuring the heat in the condensed steam and the heat given to the condensing water. The amount of heat remaining in the cylinder after cut-off can be calculated from data obtained from the indicator card.

The heated supplied to the engine from the boiler plus that contained in the clearance spaces gives the total amount of heat available. If now, from this total heat be taken the heat existing at cut-off and the equivalent heat of the work done during this period, the difference will be the loss during admission due principally to cylinder condensation.

The difference between the heat in the cylinder at cut-off and at release, after deducting the heat equivalent of work gives the heat transference during this period of expansion.

A calometric measurement of the quality of steam supplied during the test is made, and suppose that the result shows that $x\%$ is steam out of the mixture supplied. If M be the weight of mixture supplied per stroke then the heat is:–

$$Q = M[q + xr] \qquad (1)$$

where q = heat of the liquid
and r = heat of vaporization.

In the following equations the subscripts c, 0, 1, 2, 3, refer to clearance (c), beginning of ad-

mission (0), cut-off (1), release (2), beginning of compression (3).

The equations below show the heat distribution during one cycle

In the clearance

$$H_c = M_0 [q_c + x_c \rho_c] \qquad (2)$$

where ρ = heat equivalent of internal work.

At admission the weight of the mixture being still the same

$$H_0 = M_0 [q_0 + x_0 \rho_0] \qquad (3)$$

At cut-off M lbs. of mixture have been admitted therefore

$$H_1 = [M_0 + M][q_1 + x_1 \rho_1] \qquad (4.)$$

At release the mass is still the same

$$H_2 = [M_0 + M][q_2 + x_2 \rho_2] \qquad (5)$$

After exhaust has taken place and at the beginning of compression:-

$$H_3 = M_0 [q_3 + l_3 \rho_3] \qquad (6)$$

As one heat unit equals 778 ft lbs of work, the heat equivalent of external work during the cycle can be expressed as follows, where $A = \frac{1}{778}$

During admission = $A W_a$ (7)
" expansion = $A W_b$ (8)
" exhaust = $A W_c$ (9)
" compression = $A W_d$ (10)

The preceding equations of H contain values of l which are as yet unknown and before the heat distribution can be found it will be necessary to get other equations

containing x and between them solve for it.

Let V = volume in cubic feet of given weight of mixture M

σ = volume of one pound of water in cubic feet.

u = change in volume of 1 lb. of water due to conversion into steam.

Then volume of 1 lb of dry steam

$$s = u + \sigma$$

and $$V = M[xu + \sigma] \qquad (11)$$

When the clearance volume of an engine is known, the volume and pressure at any point in the cycle after the steam valve is closed can be found from the engine card. The quantity of steam used during the run and the number of strokes being known, then the average

quantity per stroke can be determined. Having this, the quality can be determined for any point of the cycle except that of clearance.

Let

$V_0 =$ clearance vol. or vol. at admission

$V_0 + V_1 =$ volume at cut off (12)

$V_0 + V_2 =$ " " release (13)

$V_0 + V_3 =$ " " compression (14)

Now as $M_0 =$ wt. of clearance steam and $M_1 =$ wt. of steam used per stroke then:—

$$V_0 = M_0 [x_c u_c + \sigma_c] \qquad (15)$$

$$V_0 + V_1 = [M_0 + M_1][x_1 u_1 + \sigma_1] \qquad (16)$$

$$V_0 + V_2 = [M_0 + M][x_2 u_2 + \sigma_2] \qquad (17)$$

$$V_0 + V_3 = M_0 [x_3 u_3 + \sigma_3] \qquad (18)$$

We will now have to assume the

value of some of the terms of the above, for each equation contains an unknown and it would be almost impossible to determine them by experiment.

The unknowns in the above are M_0, x_c, x_1, x_2, x_3 and it must be found out which would be the most proper to assume.

During the cycle of a steam engine, we known that x increases slightly during expansion due to reëvaporation of the initial condensation, then with the x at release higher than at cut off this steam has work done on it during exhaust and compression so that it is quite safe to use $x = 1$ at compression.

Therefore assuming x_0 and x_3 to be equal to unity, then from (18)

$$M_0 = \frac{V_0 + V_3}{u_3 + \sigma_3} \qquad (19)$$

x_1 and x_2 can now be found from (16) and (17)

$$x_1 = \frac{V_0 + V_1}{(M_0 + M)u_1} - \frac{\sigma_1}{u_1} \qquad (20)$$

$$x_2 = \frac{V_0 + V_2}{(M_0 + M)u_2} - \frac{\sigma}{u_2} \qquad (21)$$

Having now equations by which ~~the~~ the various unknowns can be solved, the transference of heat can be written as follows:-

Transferred during admission

$$Q_a = Q + H_0 - H_1 - AW_a \qquad (22)$$

During the period of expansion

$$Q_b = H_1 - H_2 - AW_b \qquad (23)$$

During the exhaust into the con-

densor

$$Q_c = H_2 - H_3 - M q_c - w[q_e - q_i] - A W_c \qquad (24)$$

In the above w = wt. of condensing water

q_c = heat of liquid of condensed steam

q_e = " " " " condensing water leaving

q_i = " " " " " " entering

During compression

$$Q_d = H_3 - H_0 - A W_d \qquad (25)$$

In the above equations if the algebraic sum equals zero there is no heat transferred; if the algebraic sum was a positive quantity, this gives the loss by radiation, and the sum of the losses during the different periods of the stroke gives the loss by radiation per cycle.

or $$D = Q_a + Q_b + Q_c + Q_d \qquad (26)$$

If from the total heat supplied per cycle be taken the heat exhausted and the heat equivalent of work, the result should be the same loss or

$$D = Q - Mq_c - w(q_e - q_i) - AW \qquad (27)$$

During the test the load was maintained quite heavy and the quantity of steam was so large that although the it was condensed the air pump could not hold the vacuum.

The load was taken off by a Prony brake and was kept as constant as possible.

The supply steam was tested by a Barrus calorimeter and its quality determined, while the quantity was weighed in a tank after being pumped from the condensor by the

air pump.

The heat exhausted from the engine was determined by condensing the steam in a surface condensor, and noting the temperatures of the condensed steam and of the condensing water before and after passing through the condensor. The amount of condensing water must also be determined, and this is measured over the weir.

Determination of moisture in steam

If in the mixture of steam & water in the upper part of the heat gauge of the Barrus calorimeter x parts are steam, then $(1-x)$ are moisture and the amount of heat in the mixture $= q. + x\rho.$ at the pressure $p.$. As this mixture is driven

out the pressure in back does on the mixture $x_1 A p_1 u_1 + A p_1 \sigma$ heat units of work, so that the energy in the steam above the plate

$$= q_1 + x \rho_1 + x_1 A p_1 u_1 + A p_1 \sigma$$

The last term being small the above may be written

$$q_1 + x r_1$$

The heat in the steam on the other side of the plate is

$$q_2 + r_2 + .48 [T sup - T sat]$$

Since the plate is insulated from the upper and lower heat gauges, no heat can be transferred so the heat in the two places must be equal

$$q_1 + x r_1 = q_2 + r_2 + .48 [T sup - T sat]$$

solving for x

$$x = \frac{q_2 + r_2 + .48 [T sup - T sat] - q_1}{r_1}$$

It is thus known from x the quantity of steam per pound of mixture passing through the heat gauge, and if this mixture is passed through a condensor and W lbs. are condensed, the amount of water in the steam $= W(1-x)$ But the separator during this time has collected w lbs. of moisture, so that the total weight of moisture in the steam is
$w + W(1-x)$
The total weight supplied to the instrument $= W + w$

$$\therefore \ \% \text{ Moisture} = \frac{w + W(1-x)}{w + W} 100$$

Mean gauge pressure = 94.1
" " " corrected = 94.0
Barometer = 29.97"

Atmospheric pressure $= 29.97 \times \frac{.434 \times 13.59}{12}$

$= 14.77$ lbs.

Absolute pressure $= 94.0 + 14.77$
$= 108.77$ lbs.

Mean temp. upper ther. $T_1 = 329.9° F$
" " lower " $T_2 = 286.1°$

Pressure under which steam is discharged $= 14.77 + [9.38 - 4.56] .492$

$= 14.77 * 2.37 = 17.14$ lbs.

Temp. corresponding to $108.77 = 333.71°$
Loss by radiation $= 333.71 - 329.9$
$= 3.81°$

Corrected $T_2 = 286.1 + 3.81$
$= 289.91°$

$$x_1 = \frac{1149.0 + .48\left[289.91 - 219.86\right] - 304.37}{879.41}$$

$$= \frac{1149.0 + .48 \times 70.05 - 304.37}{879.41}$$

$$= \frac{878.25}{879.41} = 0.9987 \qquad (29.)$$

Wt. of mixture discharged in 80 min.
= 87 lbs. 3 oz.
Wt. of water separated in 61 min = 9 oz

Wt. of mix. discharged in 61 min. = 1065 oz.

$$1 - x = \frac{w + W(1 - x_1)}{w + W}$$

$$= \frac{9 + 1065 \times .0013}{1074}$$

$$= .00967$$

$$x = 1 - .00967 = 99.03\%$$

Steam consumption.

Wt. of steam condensed in 59 min. = 681 lbs

" " " " per. hour

$$= \frac{681 \times 60}{59} = 692.5 \text{ lbs.}$$

Number of revolutions in 64 min. = 3769

" " " per hour = 3534

The number of lbs. of steam used per 100 revolutions is

$$\frac{692.5 \times 100}{3534} = 19.595 \text{ lbs.}$$

This amount is for both ends of the cylinder and if the cut off and clearances were the same on both ends, half would go to one end and half to the other, but this is not so.

It can be assumed that the

sum of the per cent clearance plus the per cent cut off on one end, over the per cent clearance plus the per cent cut off on both ends will give the proportion of steam going to that end

Vol. passed through by the piston

$$\text{head end} = \frac{24 \times 3.14 \times (10\tfrac{5}{32})^2}{1728 \times 4}$$

$$= 1.118 \text{ cu}'$$

$$\text{crankend} = 1.118 - \frac{24 \times 3.1416}{1728}$$

$$= 1.118 - .0436$$

$$= 1.074 \text{ cu}'$$

Per cent Clearance

head end $= \frac{.0718}{1.118} = .0642$

crank end $= \frac{.0606}{1.074} = .05642$

Cut off per cents

head = 11.0 %

crank = 13.5 %

Head $6.42 + 11 = 17.42$

Crank $5.64 + 13.5 = 19.14$

$ \overline{36.56}$

Per cent steam going to head end

$= \frac{17.42}{36.56} = 47.65\ \%$

Volumes of head end

$V_0 = .0718$ cu. ft.

$V_1 = 1.118 \times .11 = .1230$ cu. ft.

$V_2 = 1.118$ cu. ft.

$V_3 = 1.118 \frac{.64}{3.339} = .209$ cu ft.

The volumes in the cylinder up to different parts of the stroke are as follows.

Clearance Volume	V_0	$= .0718$	cu ft.
Cut-off "	$(V_0 + V_1)$	$= .1948$	" "
Release "	$(V_0 + V_2)$	$= 1.1898$	" "
Compression "	$(V_0 + V_3)$	$= .2808$	" "

The number of lbs. of steam used during 100 revolutions = 19.595 and the amount of this going to the head stroke is

$19.595 \times .4765 = 9.337 = M$

In the following calculations

the quantity of steam is that used in the head end and for 100 revolutions.

From (19)

$$M_0 = \frac{V_0 + V_3}{u_3 + \sigma} = (V_0 + V_3)\,\gamma_3$$

Although the air pump gave no vacuum it kept the back pressure down to that of the atmosphere.

$$\lambda_{14.71} = .03774$$

$$M_0 = .2808 \times .03774 = .0106 \text{ lbs per stroke}$$

Mean pressure at cut off corrected 106.5 lbs.

$$l_1 = \frac{V_0 + V_0}{(M_0 + M)\,u_{106.5}} - \frac{\sigma}{u} \qquad u = s - .016$$

$$= \frac{.1948 \times 100}{(.0106 + 9.337)(4.150 - .016)} - \frac{.016}{4.134}$$

$$= \frac{19.48}{9.3476 \times 4.134} - \frac{.016}{4.134}$$

$$= .505 - .00387$$

$$= .501$$

At release x is

$$x_2 = \frac{V_0 + V_2}{(M_0 + M)u_2} - \frac{.016}{u}$$

$$= \frac{1.1898 \times 100}{9.3476\,(16.76 - .016)} - \frac{.016}{16.744}$$

$$= .761 - .000955$$

$$= .76$$

To find x_0

$$(1 - x_0)\,.016 + x_0 s = \frac{V_0}{M_0}$$

$$x_0 = \frac{\frac{V_0}{M_0} - .016}{s - .016}$$

$$x_0 = \frac{\frac{.0718}{.0106} - .016}{4.1505 - .016} = \frac{6.754}{4.1345}$$

$$= 1.63$$

This apparently shows that the steam at this point is superheated and very much so, in fact more than it could be and the only way the result can be accounted for is that steam must leak in during compression.

If it is assumed that x_0 and x_3 are equal to 1 and solve for the masses at the respective points the difference will most probably give the weight which has leaked in.

$$M_0 = \frac{V_0}{(1-x_0).016 + x_0 S}$$

$$M_0 = \frac{.0718}{4.1505} = .0173 \text{ lbs. per stroke}$$

The previous value of $M_0 = .0106$, therefore the weight per stroke which leaks in is

$$M_0' = .0173 - .0106$$
$$= .0067 \text{ lbs.}$$

The heat which leaks in with this is:-

$$M_0'(q_{106.5} + x\, r_{106.5})$$

$$= .0067(302.65 + .9903 \times 880.6)$$

$$= .0067 \times 1174.71$$

$$= 7.871 \quad H.U.$$

Heat per 100 strokes $= 100 \times 7.871$

$$= 787.1 \ H.U.$$

In finding the heat equivalent of work from the areas of the cards

it is convenient to determine the constant of it.

$$K = \frac{\text{height} \times \text{length} \times \text{scale} \times \text{area pis} \times \text{stroke}}{\text{mean length of card} \times 12''}$$

$$= \frac{a \times 40 \times 81.04 \times \cancel{24}^{2} \times 100}{3.339 \times \cancel{12}}$$

$$= 194160\ a$$

The mean areas of the mean card are

Area of admission $(0, 1, d, e)$ = 1.005 sq"

Area of expansion $(1, 2, b, d)$ = 2.91 sq"

Area of exhaust $(a, b, c, 3)$ = 1.01 sq"

Area of compression $(e, b, 3, c)$ = .535 sq"

The work is as follows:-

$W_a = 194160 \times 1.005$

$W_a = 195137$ ft. lbs.

$W_b = 194160 \times 2.91$

$= 566325$ ft. lbs.

$W_c = 194160 \times -1.01$

$= 196110$ ft lbs.

$W_d = 194160 \times .535$

$= 103879$ ft. lbs.

The heat equivalents of the above are

$AW_a = \dfrac{195137}{778}$

$= 250.8$ H.U

$AW_b = \dfrac{566325}{778}$

$= 727.9$ H.U

$AW_c = \dfrac{196110}{778}$

$= 252.1$ H.U.

$$A W_d = \frac{103,879}{778}$$

$$= 133.52 \text{ H.U.}$$

$$W_a + W_b = 195137 + 566325$$

$$= 761462 \text{ ft. lbs.}$$

$$W_c + W_d = 196110 + 103879$$

$$= 299989 \text{ ft lbs.}$$

$$W = (W_a + W_b) - (W_c + W_a)$$

$$= 761462 - 299989$$

$$= 461473 \text{ ft. lbs.}$$

$$A W = \frac{461473}{778}$$

$$= 593.2 \text{ H.U.}$$

The heat supplied to the engine per 100 strokes is

$$M \left(q_{106.5} + x \, r_{106.5} \right)$$

$Q = 9.337\,(302.65 + .9903 \times 880.6)$

$= 9.337 \times 1174.71$

$= 10968$ H.U.

The number of lbs. of steam used on the head end per 100 strokes = 9.337
The mean temperature of the condensed steam = 121.3° F

∴ Heat in condensed steam = $M\,q_{121.3}$

$= 9.337 \times 89.4$

$= 779.2$ H.U.

The weight of condensing water by weir measurement.

Mean breadth = 7.344"

" head = 1.853

$Q_w = \frac{2}{3}\, c\, \sqrt{2g}\; b\; H^{3/2}$

$= .666 \times .604 \times 8.01 \times \frac{7.344}{12} \times \left(\frac{1.853}{12}\right)^{3/2}$

$= .11977$ cu ft per sec.

$Q_w = .11977 \times 60 \times 60$
$= 431.17$ cu ft per hr.

Mean temperature of the ejected water was 115°F

Weight of 1 cu. ft. at 115° = 61.79 lbs.

∴ lbs of water per hr = 431.17×61.79
$= 26642$ lbs.

Now the number of revolutions made in one hour = 3534

∴ Cond. H_2O per 100 rev = $\frac{26642}{3534}$

$= 753.9$ lbs.

Heat given to condensing water

$w(q_{115} - q_{90.9}) = 753.9(83.0 - 58.93)$

$= 18146.4$ HU

This is for both ends for

head end = $18146.4 \times .4765 = 8645$ HU

The quantity of heat at different points in the cycle are

In clearance

$$H_0 = (M_0 + M_0')(q_{106.5} + \rho_{106.5})$$

$$= 100\,(.0106 + .0067)(302.65 + 799.1)$$

$$= 1906 \text{ H.U.}$$

At beginning of expansion. The M includes the steam taken in during compression.

$$H_1 = 100\,(M_0 + M)(q_{106.5} + x_1\rho_{106.5})$$

$$= 100\,(.0106 + .09337)(302.65 + .501 \times 799.1)$$

$$= 7310 \text{ H.U.}$$

At release

$$H_2 = 100\,(M_0 + M)(q_{24} + x_2\rho_{24})$$

$$= 100\,(.0106 + .09337)(206.8 + .761 \times 873.2)$$

$$= 9058.8 \text{ H U}$$

At the beginning of compression

$$H_3 = 100 M_0 \left(q_{14.77} + \rho_{14.77} \right)$$

$$= 100 \times .0106 \left(181.0 + 893.3 \right)$$

$$= 1138.7 \text{ H.U.}$$

The heat admitted during admission is

$$Q_1 = (M - M_0')(q_{106.5} + x r_{106.5})$$

$$= (9.337 - 1.06)(302.65 + .9903 \times 880.6)$$

$$= 10181 \text{ H.U.}$$

Transfer of heat

During admission

$$Q_a = Q_1 + H_0 - H_1 - AW_a$$

$$= 10181 + 1906 - 7310 - 250.8$$

$$= 4526.2 \text{ H.U.}$$

During expansion

$$Q_b = H_1 - H_2 - AW_b$$

$$= 7310 - 9058.8 - 727.9$$

$$= -2476.7 \text{ H.U.}$$

During exhaustion

$$Q_c = H_2 - H_3 - Mq_c - w(q_e - q_i) + AW_c$$

$$= 9058.8 - 1138.7 - 779.2 - 8645 + 252.1$$

$$= 9310.9 - 10562.9$$

$$= -1252.0 \quad H.U.$$

During compression

$$Q_d = M_0(q_{14.77} + \rho_{14.77}) + M_0'(q_{106.5} + x r_{106.5}) + AW_d$$
$$- (M_0 + M_0')(q_{106.5} + \rho_{106.5})$$

$$= 100 \times .0106\,(181.0 + 893.3) + 100 \times .0067(302.65 +$$
$$.9903 \times 880.6) + 133.52 - .0173(302.65 + 799.1)\,100$$

$$= 153.38 \quad H.U.$$

Loss by radiation

$$D' = Q_a + Q_b + Q_c + Q_d$$

$$= 4526.2 - 2476.7 - 1252.1 + 153.38$$

$$= 950.9 \quad H.U.$$

The loss by radiation can also be written

$$D = Q - Mq_c - w(q_c - q_i) - AW$$
$$= 10968 - 779.2 - 8645 - 593.2$$
$$= 10968 - 10017.4$$
$$= 950.6 \text{ H.U.}$$

Percentages of Losses.

During admission

$$L_a = \frac{Q_a}{Q} = \frac{4526.2}{10968}$$

$$= .4127$$

During expansion (restored)

$$L_b = \frac{Q_b}{Q} = \frac{2476.7}{10968}$$

$$= .2258$$

During exhaust

$$L_c = \frac{Q_c}{Q} = \frac{1251}{10968}$$

$$= .1141$$

During compression

$$L_d = \frac{Q_a}{Q} = \frac{153.38}{10968}$$

$$= .1399$$

Ratio of utilized work to total heat

$$R_1 = \frac{AW}{Q} = \frac{593.2}{10968}$$

$$= .0542$$

Per cent lost by radiation

$$R_2 = \frac{D}{Q} = \frac{950.7}{10968}$$

$$= .08668$$

Per cent radiation of work

$$R_3 = \frac{D}{AW} = \frac{950.7}{593.2}$$

$$= 1.603$$

Ratio of cylinder condensation to work

$$R_4 = \frac{Q_a}{AW} = \frac{4526.2}{593.2}$$

$$= 7.64$$

Carnots Efficiency

$$E = \frac{T_{106.5} - T_{14.77}}{T_{106.5}} = \frac{332.18 - 212.23}{332.18 + 460.7}$$

$$= \frac{119.95}{792.88} = .1513$$

Type Efficiency.

$$E' = \frac{R_1}{E} = \frac{.0542}{.1513}$$

$$= .358$$

Horse Powers.

Head:–

$$HP = \frac{PLAN}{33000} = \frac{2.370 \times 40 \times 81.04 \times 3534 \times 2}{3.339 \times 33000 \times 60}$$

$$= 8.214$$

Crank:–

$$HP = \frac{2.758 \times 40 \times 2 \times 77.9 \times 3534}{3.304 \times 33000 \times 60}$$

$$= 9.285$$

$$\text{Total } HP = 8.214 + 9.285$$

$$= 17.499$$

Steam per H.P. hour

$$= \frac{692.5}{17.499} = 39.57 \text{ lbs.}$$

Entropy-Temperature.
Analysis.

From the data already derived, it is known that the steam used during an engine cycle consists of two portions; 1st, the clearance or "cushion" steam which is present in the cylinder during ~~during~~ every part of the stroke, and 2nd, the feed or supply steam, which while entering, and later during expansion, does work, and is then discharged, still having a large amount of heat in it.

In Hirn's analysis the determinations were for 100 revolutions, in this analysis they are for one pound of steam or per pound of cylinder

feed.

The weight of steam per stroke on head end = .09337 lbs.

The reciprocal of this is the number of revolutions per lb. of steam or $\frac{1}{.09337} = 10.71$

The volume of piston displacement for one pound of steam is

Head = $10.71 \times 1.118 = 11.974$ cu. ft.

The weight of cushion steam, head end, for one pound of feed is

Wt. of clearance steam × no. of rev. per lb. feed = $.0106 \times 10.71$

$= .1135$ lbs.

The clearance volume for one pound of feed steam

Head = $.0718 \times 10.71$

$= .7690$ cu. ft.

Turning to the blue print made from the diagram accompanying Reeve's pamphlet it is found to be divided into four quadrants by four rectangular axes of coördinates. The right hand horizontal one measures volume, the lower vertical one pressure, the left hand horizontal temperature and the upper vertical entropy.

In the lower left hand quadrant are a number of adiabatic curves for diffrent weights of clearance steam. They are developed from saturation points of steam at 41.6 pounds absolute pressure, which is the pressure at which 1 lb. of steam dry and saturated occupies 10 cu. ft.

As these curves fall below 41.6

lbs. pressure, partial condensation occurs and the amount in per-cent is noted at the extreme left.

Now the clearance steam was measured at 14.77 lbs. absolute, and the per. cent corresponding to it is 94% so weight is

$$\frac{.1135}{.94} = .1206 \text{ lbs.}$$

A curve is now drawn in between the .10 and .15 lb curves corresponding to .1206 lbs.

This curve will be the actual path up and down which the clearance steam expands and compresses adiabatically.

The clearance volume for one lb. of feed steam is

head = .769 cu'.

This value laid off to scale hori-

zontally to the right from the above curve, will give the zero curve of piston displacement, and from it the abscissa of the indicator cards must be measured.

The abscissa of the mean card for different pressures are now taken, and after being multiplied by the volume scale laid off to the right.

Length of mean card = 3.339"

Piston displacement for 1 lb of steam = 11.974

∴ 3.339" = 11.974 cu'

Scale = 1" = 3.587 cu'

From the abscissa now laid off erect the corresponding pressures and through the points found draw the card.

Now that the card is drawn the entropy temperature diagram can

be found from it and the method of making the transfer is shown on the blue print for the two points u and v, other points being found in exactly the same way.

The area DAJN in the entropy temperature quadrant represents the card from the theoretical engine.

The actual card from this engine is BFKLMGC. The point of cut off is B and as $\overline{BC}$ is vertical there is no wire drawing.

If after cut off the steam expanded adiabatically to the condenser temperature it would trace the diagram DBON instead of BAJN. The area BAJO is loss due to initial condensation.

Condensation during expansion is

represented by BQPO

The steam instead of expanding adiabatically deviated to the point K. This gain in entropy is due to heat coming from the cylinder walls and is called the gain of re evaporation and is QPRK.

The loss of incomplete expansion is represented by KRPL.

Loss from clearance is SDCM.

Loss from back pressure LPNS.

The above areas are now found in sq. inches, and if the blue print was the same as the original diagram, the areas in inches multiplied by 4421.88 would give results in foot pounds of work.

The blue print has however shrunk a little and the amount is found by

getting the area of a certain figure on the original print, and then finding the area of the same figure on the blue print.

Area of original, mean = 7.956

" " blue print, " = 7.951

Therefore multiply the areas by

$$\frac{7.956}{7.951} = 1.0005$$

READINGS

CALORIMETER

TIME	STEAM PRESSURE	UPPER THERM. T_1	LOWER THERM. T_2	BAROM.–	MERCURY GAUGE R	L
2.45	94	330	284	29.97"	9.35	4.55
2.52	94	329	286		9.35	4.55
3.02	96	331	287		9.45	4.50
3.11	93	329	286		9.30	4.60
3.20	93	329	286		9.35	4.55
3.28	95	331	287		9.45	4.55
3.39	95	330	287		9.45	4.55
3.49	93	330	286	29.97	9.35	4.60
64	94.1	329.9	286.1	29.97	9.38	4.56

MEANS

CALORIMETER

W			w.		
TIME	WEIGHT EMPTY	WEIGHT FULL	TIME AT MARK	WEIGHT EMPTY	WEIGHT FULL
2.42	2 - 14				
2.58	3 - 13	19 - 4			
3.15	2 - 14	22 - 9	3.03	0 - 7.5	0 - 14
3.33	3 - 14	22 - 12			
3.47	2 - 14	18 - 15			
4.02		20 - 0	4.04	0 - 8.5	0 - 11
	16 - 5	103 - 8		0 - 16	0 - 25
80		87 - 3	61		0 - 9

TIME	REVOLUTIONS	BRAKE
2.45	25786	510
2.52	26195	502
3.02	26789	502
3.11	27315	501
3.20	27845	500
3.28	28316	500
3.39	28966	500
3.49	29555	500
64	3769	501.9

CONDENSED STEAM.

WEIGHT EMPTY	TIME	WEIGHT FULL	TIME	TEMP.
408	2.46	484	2.47	118
		597	3.03	120
		658	3.08	121
179	3.12	289	3.21	122
		378	3.29	122
		507	3.40	123
		610	3.49	123
	WEIGHT	681	59	121.3

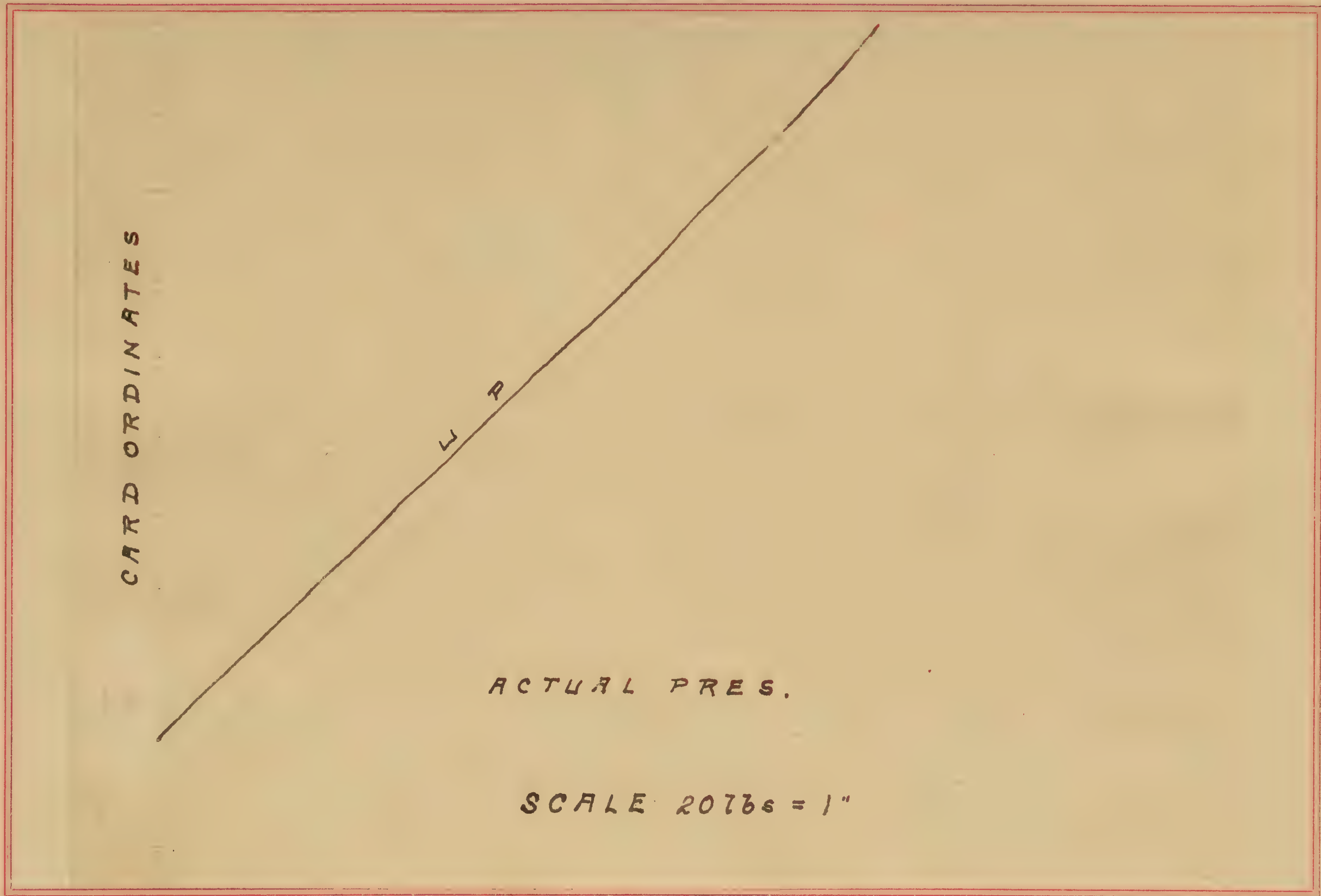
CONDENSING WATER

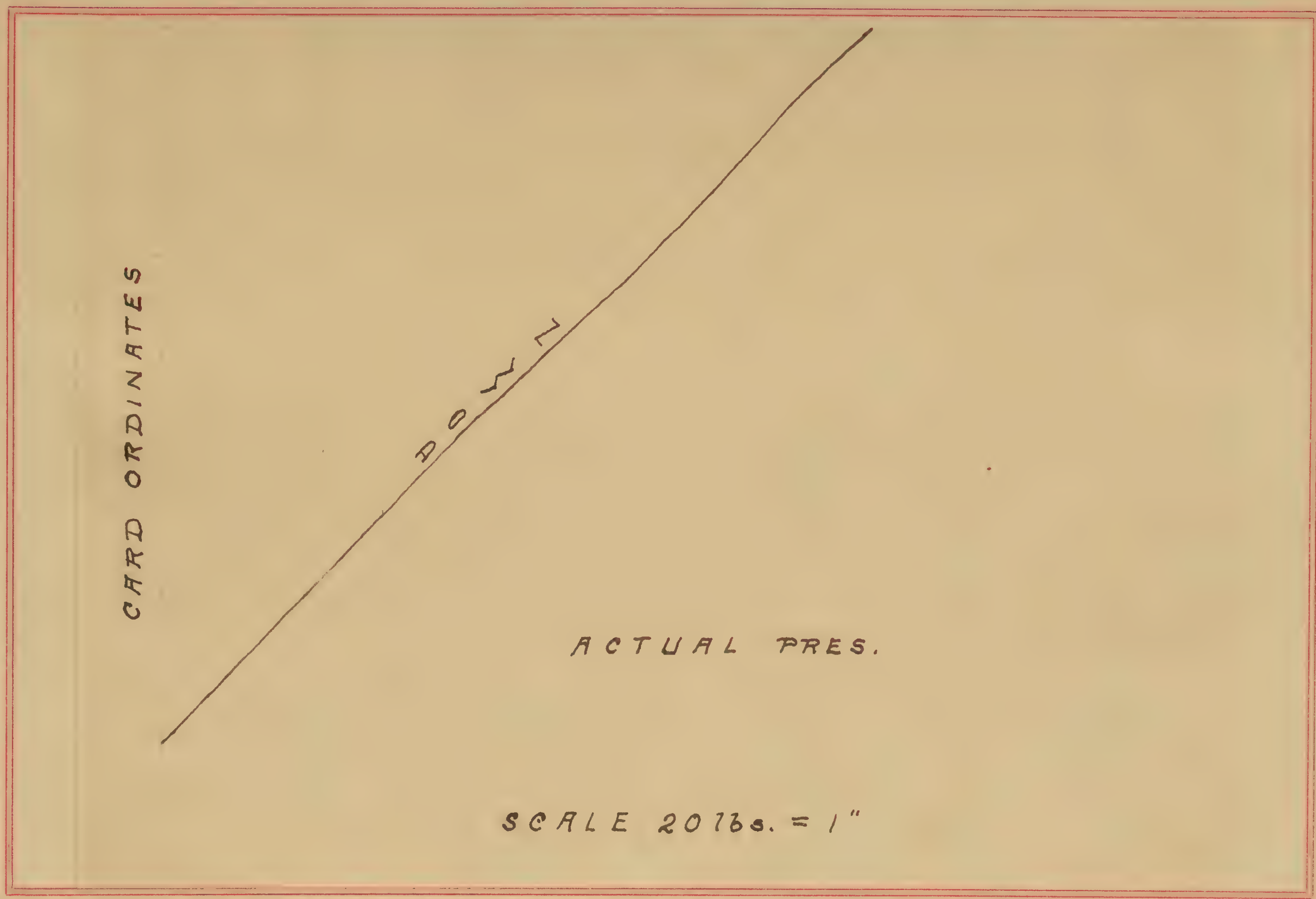
TIME	HOOK GAUGE	ZERO OF GAUGE	TEMP. INJECTION	TEMP. EJECTION
2.47	9.97	11.825	87°	110
3.03	9.97		87	112
3.08	9.98		89	114
3.21	9.98		91	115
3.29	9.95		92	116
3.40	9.98		94	118
3.49	9.98	HEAD	96	120
	9.972	1.853	90.9	115

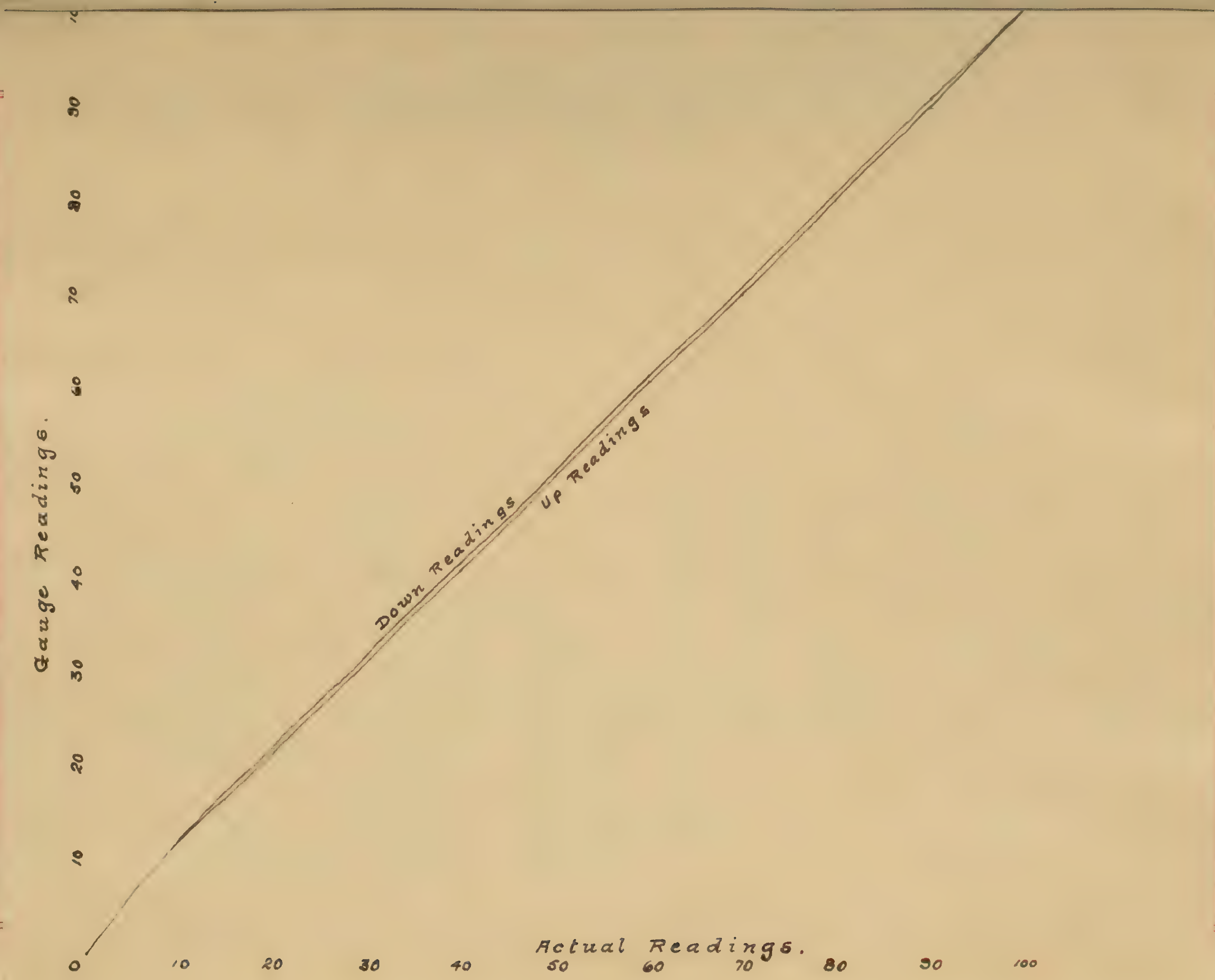
CALIBRATION OF

GAUGE No. 260627

ACTUAL	GAUGE UP	GAUGE DOWN	MEAN
10	12.0	12.0	12.0
20	21.0	21.6	21.30
30	31.3	32.0	31.65
40	40.6	41.5	41.05
50	50.5	51.0	50.75
60	60.5	61.2	60.85
70	69.7	70.5	70.10
80	79.9	80.5	80.20
90	89.6	90.2	89.90
100	100.0	100.0	100.0


CARD ORDINATES
L
A
ACTUAL PRES.
SCALE 20lbs = 1"


CARD ORDINATES
DOWN
ACTUAL PRES.
SCALE 20 lbs. = 1"



Gauge Readings.
Actual Readings.
Down Readings
Up Readings
0
10
20
30
40
50
60
70
80
90
100

CARD LENGTHS, HEAD END.

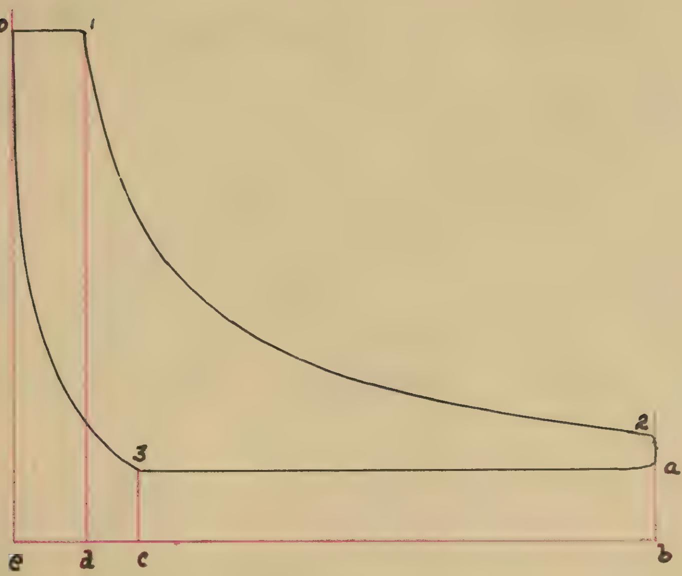
CARD	ADMISSION	EXPAN.	EXHAUST	COMP.	TOTAL
1	0.43	2.90	2.64	0.69	3.33
3	0.48	2.91	2.68	0.66	3.34
5	0.36	2.98	2.72	0.62	3.34
7	0.43	2.92	2.72	0.63	3.35
9	0.31	3.03	2.66	0.68	3.34
11	0.43	2.90	2.69	0.64	3.33
13	0.33	3.02	2.73	0.62	3.35
15	0.36	2.97	2.73	0.60	3.33
17	0.23	3.11	2.72	0.62	3.34
MEANS	0.368	2.971	2.699	0.640	3.339

CARD LENGTHS, CRANK END.

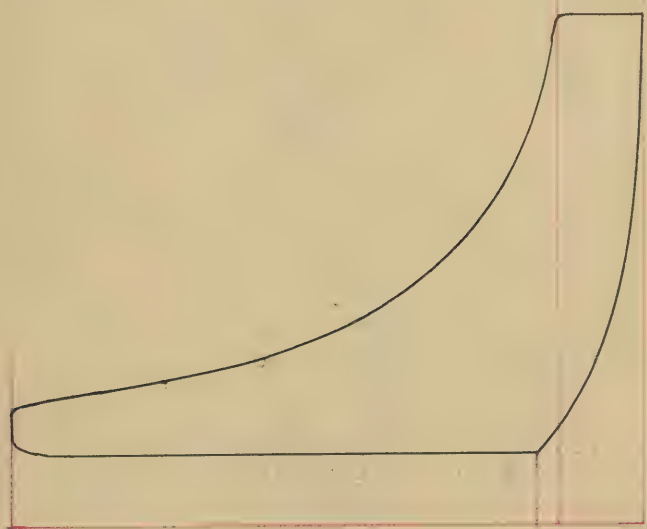
CARD	ADMIS.	EXPAN.	EXHAUST	COMP.	TOTAL
2	0.48	2.83	2.66	0.65	3.31
4	0.49	2.81	2.71	0.59	3.30
6	0.47	2.82	2.71	0.58	3.29
8	0.52	2.70	2.72	0.60	3.32
10	0.43	2.86	2.73	0.56	3.29
12	0.45	2.85	2.72	0.58	3.30
14	0.34	2.99	2.79	0.54	3.33
16	0.48	2.83	2.72	0.59	3.31
18	0.35	2.94	2.72	0.57	3.29
MEANS	0.446	2.846	2.720	0.584	3.304

AREAS OF MEAN CARD.

ADMIS.	EXPAN.	EXHAU.	COMP.	TOTAL
1.00	2.93	1.01	.53	
.99	2.91	1.00	.54	
1.02	2.90	1.03	.55	
.99	2.90	1.01	.52	
1.03	2.91	1.00	.53	
1.005	2.91	1.01	.535	2.370



MEAN CARD FROM HEAD

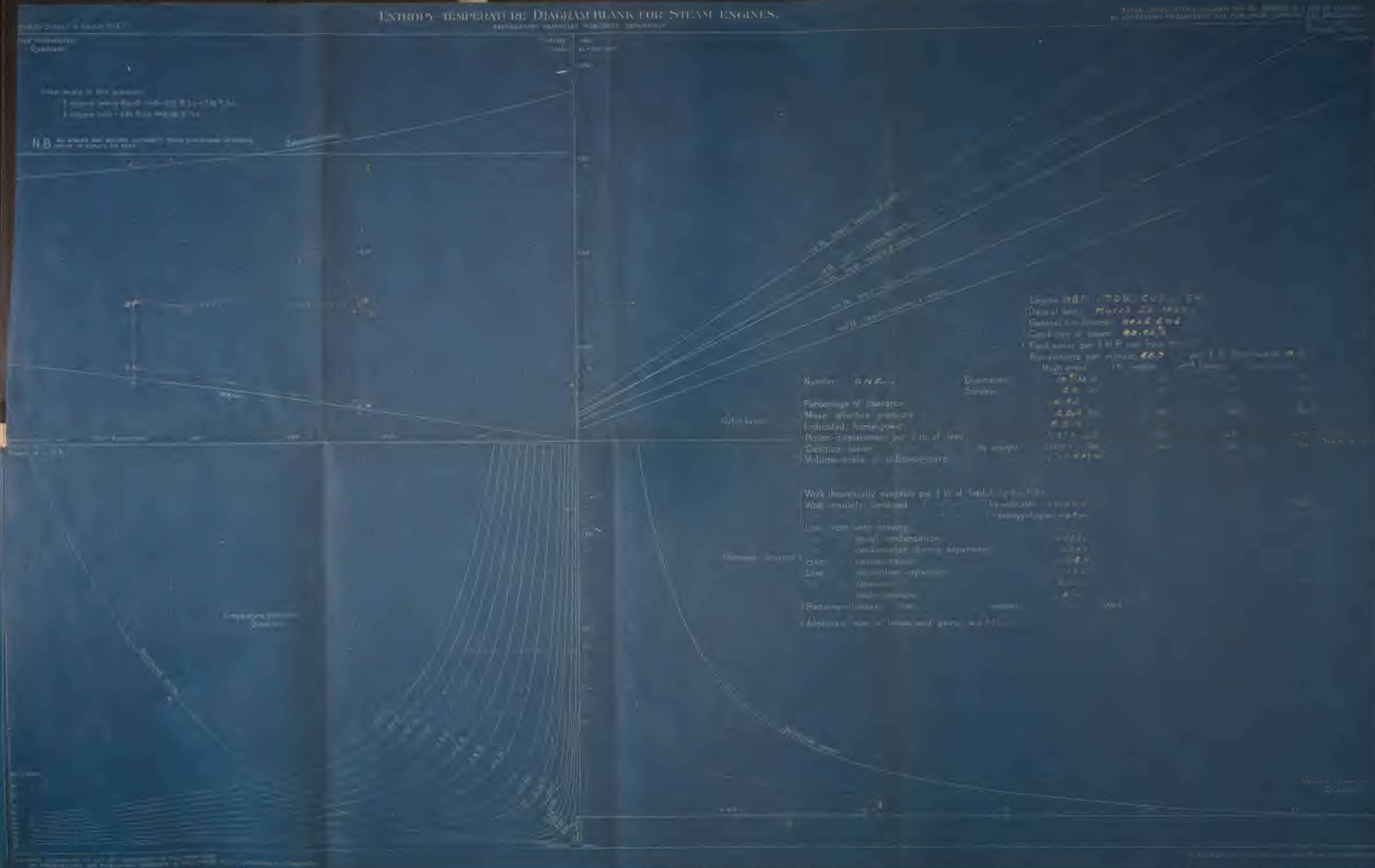


MEAN CARD FROM CRANK

AREAS OF

ENTROPY TEMPERATURE DIAGRAM.

DAJN	BFKLMGC	BAJO	BQPO	QPRK	KRPL	SDCM	LPNS
24.71	10.64	14.52	0.58	2.45	0.48	0.75	0.14
24.59	10.70	14.56	0.53	2.57	0.46	0.73	0.14
24.64	10.74	14.54	0.59	2.48	0.48	0.73	0.17
24.64	10.67	14.62	0.54	2.44	0.53	0.74	0.13
24.72	10.73	14.52	0.53	2.45	0.50	0.76	0.12
24.660	10.696	14.552	0.554	2.466	0.490	0.742	0.150



Entropy-temperature Diagram Blank for Steam Engines.
Explanatory pamphlet published separately
Extra copies of this diagram may be obtained
By addressing Progressive Age Publishing Company
N.B.
Date tested: March 22, 192
General conditions: Head End
Condition of steam: 88.64%
Feed water per I.H.P. per hour
Revolutions per minute 68.5
Number
Diameter
Stroke
Percentage of clearance
Mean effective pressure
Indicated horse-power
Piston-displacement per 1 lb. of feed
Cushion-steam
by weight
Volume-scale of indicator-card
Cylinders
Work theoretically available per 1 lb. of feed
Work actually developed
by indicator
Loss from wire drawing
initial condensation
condensation during expansion
Gain
re-evaporation
Loss
incomplete expansion
Receiver-losses
Algebraic sum of losses and gains
Temperature-pressure Quadrant
Volume-pressure Quadrant
Published by Progressive Age Pub. Co. New York